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Ethno-ecological evidence for *Hydnora abyssinica* occurring in Johannesburg and Durban traditional medicine markets

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Abstract

Large quantities of plants are traded annually in South Africa's traditional medicine or '*muthi*' markets. A resource in high demand in the Faraday (Johannesburg) and Warwick (Durban) markets is *uMavumbuka*, a root holoparasite usually identified as either *Hydnora africana* Thunb. or *Sarcophyte sanguinea* Sparrm. subsp. *sanguinea*. However, rhizomes regularly observed in Faraday between 1994 and 2008 did not resemble either species, thereby suggesting that a third, and undocumented, species was being harvested. This was confirmed when the rhizomes were identified as *H. abyssinica* A.Br. by an American parasitic plant expert. An ethno-ecological study was initiated to verify its occurrence in selected *muthi* markets. The study further aimed to investigate the distribution of *H. abyssinica* through trader interviews, host species localities and some previously misidentified herbarium specimens. The study revealed that *H. abyssinica* was the only *uMavumbuka* species present in Faraday and Warwick in 2009. Furthermore, the rhizomes were being harvested in KwaZulu-Natal—an area not previously known to be part of its distribution range. Re-evaluated herbarium vouchers and recent photographs taken in the Kruger National Park have confirmed that *H. abyssinica* occurs in KwaZulu-Natal, Limpopo, Mpumalanga, Gauteng and Swaziland and hence eastern southern Africa. Fragments of *Acacia xanthophloea* Benth. roots were identified on 93% of the samples that had host roots attached, and we suspect that *H. abyssinica* follows the distribution of *A. xanthophloea* in suitable habitats north from KwaZulu-Natal and adjoining the South African border with Swaziland and Mozambique. *Acacia karroo* Hayne and *A. grandicornuta* Gerstner have also been positively identified as host species in South Africa from herbarium records. Plant harvesters in the markets cited the common names of several other species that *uMavumbuka* "grows under" that may be identified as hosts to *H. abyssinica* in the future. The collection of specimens in areas identified by the harvesters and in areas of suitable habitat is important to verify the occurrence, distribution and habitat of *H. abyssinica* in eastern southern Africa.

Keywords: *Acacia*; Distribution; Ethnobotany; Harvesting; Holoparasite; *Hydnora abyssinica*; *Hydnora africana*; *Sarcophyte sanguinea*; Parasitic plants; Traditional medicine

1. Introduction

The trade in traditional medicine, or *muthi*, plays an important role in the South African economy and the lives of a large proportion of South African consumers (Mander et al., 2007). The annual value *c.*2007 was estimated at R2.9 billion, representing 5.6% of the National Health budget (Mander et al., 2007). Traditional medicines are mostly harvested from the wild, and many veteran harvesters and traders have a good understanding of plant availability and distribution (Cunningham, 1991; Williams, 2007).

There are more than 771 plant species traded in South African *muthi* markets (Mander et al., 2007). One plant recorded in the markets of KwaZulu-Natal (KZN), Gauteng, Eastern Cape and Mpumalanga is *uMavumbuka* (Botha et al., 2001; Cunningham, 1988; Dold and Cocks, 2002; Dold et al., 2003; Pooley, 1998; Williams, 2004, 2007; Williams et al., 2001, 2007), a Zulu word meaning "the one that pops up". *uMavumbuka* is the common name for a root parasite previously identified as either *Hydnora africana* Thunb. or *Sarcophyte sanguinea* Sparrm. subsp. *sanguinea.* When A.B. Cunningham

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first encountered *Hydnora* in KZN, he identified it as *H. africana*; however, he admitted to doubting the traders' insistence that the plants had been harvested in KZN since the species was only known to occur in the Western and Eastern Cape Provinces in South Africa (Cunningham, 1988). Several months later, however, *Hydnora* sp. rhizomes collected in KZN by traditional medicine gatherers (*Cunningham 2520* NH, NU) were registered as the 'first record' of the genus in the province (Cunningham, 1988).

Rhizomes called *uMavumbuka* that bore a slight, but not exact, resemblance to *H. africana*, and were apparently harvested from Limpopo and KZN, were observed in large quantities on regular visits to the Faraday *muthi* market in Johannesburg between 1994 and 2008 (V.L. Williams, pers. obs.). The rhizomes sold in Faraday were cylindrical rather than angular in cross-section, and had a random rather than regular arrangement of 'bumps' or warty outgrowths. These observations suggested that a third, and undocumented, species of *uMavumbuka* was being harvested. The same undocumented species was also observed in a market near Liwonde, Malawi in 2005 (V.L. Williams, pers. obs.). In 2007, photographs of the plants observed in Johannesburg and Malawi were sent to Professor L.J. Musselman from Old Dominion University, USA, an expert on parasitic flora. He identified the rhizomes as *H. abyssinica* A. Br., a widespread species occurring from Namibia across sub-Saharan Africa to the Arabian peninsula (Musselman and Visser, 1989). Hence, the ethno-ecological trade records from the *muthi* markets in Johannesburg and Malawi were indicating that *H. abyssinica* could occur in eastern southern Africa and thus further south and east than previously known from herbarium specimens. This new evidence lead to the initiation of an ethno-ecological study in 2009 to: 1) identify which species of *uMavumbuka* were being traded, 2) confirm the presence of *H. abyssinica* in the *muthi* markets; 3) ascertain the possible geographic occurrence of the species using trader information on where the rhizomes were being harvested, and 4) infer the distribution of the species harvested by examining the distributions of the host species cited by the *muthi* traders.

2. Species descriptions

2.1. uMavumbuka morphology

Hydnora spp. are subterranean root holoparasites with a plant body that is rhizome- and root-like. There are currently five species recognised—*H. abyssinica* A.Br. (= *H. johannis* Becc. = *H. solmsiana* Dinter), *H. africana* Thunb., *H. esculenta* Jum. & H.Perrier, *H. triceps* Drège & E.Mey. and *H. sinandevu* Beentje & Q.Luke (Tennakoon et al., 2007). The body of *Hydnora* spp. consists of vegetative and reproductive structures; however, there is no evidence of root-like structures (e.g. root hairs) and tissues (e.g. endodermis, pericycle, casparian strip, and protostele) (Tennakoon et al., 2007). The genus has extremely reduced vegetative features, hence the homology of the vegetative body is difficult to interpret based on the absence of clearly distinguishable stem, root and leaf parts (Bolin et al., 2009; Tennakoon et al., 2007). The term 'rhizome' in the sense of Tennakoon et al. (2007) is used in this paper to describe the underground vegetative body of *Hydnora* spp.

H. abyssinica and *H. africana* primarily differ in the shape of the rhizome, the arrangement of the warty outgrowths (or "bumps"; Fig. 1A,B), the number of perianth lobes, stamens and stigmas, and the position of the osmophores (odour producing bodies) (Table 1). In addition, the four perianth lobes of *H. abyssinica* are fully separated and tend to lie flat on the ground during wet weather. In contrast, *H. africana* usually has 3 perianth lobes that are attached to the tips in a ball-like arrangement. However, the perianth lobes of *H. abyssinica* are often only slightly separated under drier conditions (Musselman, 1997) and when emerging, and this may cause the flowers to be confused with those of *H. africana*. Flower emergence for *Hydnora* spp. is usually dependent on the onset of rain (Musselman, 1997). *S. sanguinea* differs from *Hydnora* spp. in that the tuber is irregularly lobed (Fig. 1C) and plants are dioecious (Visser, 1981).

The vegetative and fruiting bodies of *Hydnora* spp. are reported to be hypogeous in nature, i.e. entirely subterranean, with the flowers being the only structures that emerge from the soil (Musselman and Visser, 1989; Seymour et al, 2009) (Table 1). However, a photograph taken of a subpopulation of *H. abyssinica* in Botswana by A.B. Cunningham shows the occurrence of epigeous fruits [i.e. growing close to the ground, in the sense of Stearn (1966)], with the remains of the floral tube (Fig. 2B). Results from this study further indicated that harvesters sometimes look for epigeous fruits to locate the subterranean rhizomes. Hence, there is evidence that subpopulations with forms of *H. abyssinica* with epigeous fruits occur in southern Africa. Also variable on *H. abyssinica* rhizomes is the size and shape of the warty outgrowths or 'bumps'. The bumps are mostly 3–4mm and star-shaped, however specimens

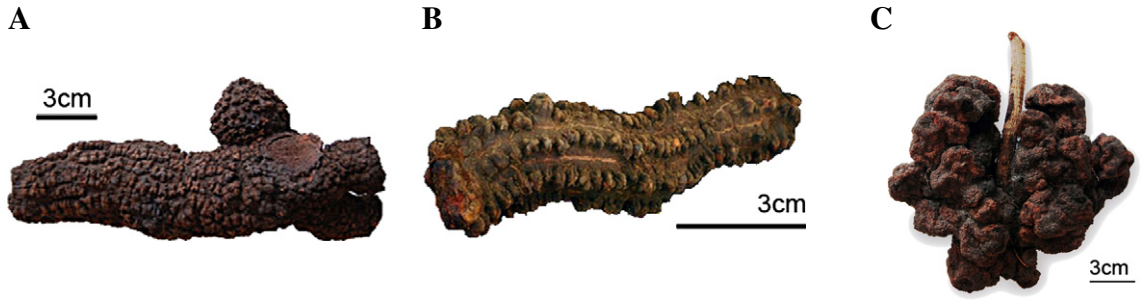

Fig. 1. Vegetative bodies of *uMavumbuka*: (A) *Hydnora abyssinica* and (B) *H. africana* (*Dold s.n.* J) showing the difference in the arrangement of the "bumps" or warty outgrowths; (C) *Sarcophyte sanguinea* subsp. *sanguinea* attached to *Acacia caffra* root (*Wojtasik 5* J).

Table 1
Main morphological characteristics and distinguishing features of *Hydnora abyssinica* and *H. africana*. Terminology used to describe the vegetative body is based on Tennakoon et al. (2005, 2007).

Plant characteristics	*Hydnora abyssinica*	*Hydnora africana*
Distribution		
	From South Africa (Northern Cape, Limpopo, Gauteng, KwaZulu-Natal; Fig. 3) and Swaziland across sub-Saharan Africa to the Arabian peninsula[1,2,3] Recently reported in southern Mozambique [26]	From southern Angola, down the Cape coast and around to the Eastern Cape and southern KwaZulu-Natal [3,4,5,22]
Vegetative body morphology		
Vegetative body	Entirely subterranean (hypogeous) rhizome- and root-like holoparasite, usually with massive ramified rhizome system spreading parallel and laterally from the host. Has extremely reduced vegetative morphology, therefore an absence of clearly distinguishable stem, root and leaf parts. Sticky red exudate when fresh. Perennial.[4,5,6,7,8,9,10,11, 25]	
Periderm	Verrucose i.e. with warty/tuberous outgrowths ('bumps'); dark brown and woody when dry.[5,6,8,9,10,11]	
Inner rhizome colour	Firmly-fleshy and brick-red or reddish-pink.[5,7,8,9,10,11]	
Rhizome shape	Terete/cylindrical in cross-section, sometimes flattened[2,5,7,8,9,10,11,12,13]	4–7 angled in cross-section, but mostly 5–6 angled[5,9,13,14,15]
Arrangement of 'bumps' on rhizome	Random and irregular (Fig. 1A).[2,7,9]	In rows on ridges of primarily 5–6merous rhizome (Fig. 1B).[6,9,14]
'Bumps'	Majority of 'bumps' dormant. Bumps occasionally differentiate into flower buds, lateral branches or haustoria (the latter after contact with a host root). Exogenous in origin.[4,6] Size and shape observed to vary in *H. abyssinica*.	
Rhizome diameter	to 12 cm[16]	to 5 cm[15]
'Roots'	The thickened lateral rhizome and the warty bumps have historically been described as "pilot roots" and "haustorial roots" respectively [(e.g. 14,16,17,20,21)]. However, the vegetative body does not possess specific root-like structures and tissues and the bumps are not haustorial "roots". [4,6]	
Host species (in southern Africa)	*Acacia* spp.; *A. grandicornuta* [3]; *A. karroo* [3,10,17]; *A. luederitzii* var. [10]; *A. nigrescens* [3]; *A. nilotica* subsp. [3]; *A. rehmanniana* [3]; *A. tortilis* subsp. [10,19]; *A. xanthophloea* [2,3,19]	*Euphorbia* spp.; *E. caput-medusae* [5]; *E. coerulans* [3]; *E. decussata* [5]; *E. gummifera* [4,5]; *E. gariepina* subsp. [3].; *E. gregaria* [4]; *E. karroensis* [5]; *E. lignosa* [5]; *E. mauritanica* var. [3,4,5,6,14]; *E. tirucalli* [18]; *E. triangularis* [3]
Flower morphology		
Characteristics	Epigeous; epigynous; bisexual; protogynous chamber flowers with an androecial chamber and subtending gynoecial chamber (Fig. 8); emerge above ground from 'bumps' that develop into buds on the subterranean rhizome; usually emerge after rain; has odour similar to carrion attracting mainly Coleopteran pollinators. [1,12,21,22,25]	
Perianth lobes	4-merous (rarely 3 or 5) (Figs. 7,8); fleshy; often fully patent and resting on soil in wet weather, otherwise connivent or connate at tips in early stages or dry weather. [7,8,9,10,11]	3-merous (rarely 2 or 4); fleshy; lobe margins connate/joined at the tips. [1,9,14]
Stigma	4-lobed; sessile, forms a cushion at base of gynoecial chamber above the ovary (Fig. 8); distinct grooves on surface. [7,8,9,10,11]	3-lobed; sessile, forms a cushion at the base of the gynoecial chamber above the ovary (±1.6 cm wide); grooves on surface. [1,10]
Ovary	Inferior; unilocular; placentae suspended from gynoecial cavity. [1,5,7,9,10,13]	
Odour origin	Osmophores on tips of perianth lobes (Figs. 7,8)[10,22]	Elongated osmophores recessed on inner surface of perianth lobes[1,10,22]
Fruit		
Characteristics	Both species reported in the literature to have entirely subterranean fruit. However, we have photographic evidence of epigeous fruits from an *H. abyssinica* subpopulation in Botswana (Fig. 2B), and anecdotal reports that plant harvesters from Manguzi (KZN) look for epigeous fruits to find the hypogeous rhizomes. Outer periderm scaly; 4-lobed grooved stigma 'scar' marking the attachment of the floral tube evident on top of the dry *H. abyssinica* fruit (Fig. 2A). [5,7,8,9,10,11,25]	
Maturation	About 5 months[9]	1–2 years[1,14,21]
Diameter	4–15 cm[2,9,10,23]	7–12 cm[21,24]

[1] Bolin et al., 2009; [2] Wojtasik, 2009; [3] Specimens from PRE, NH, PUC, KNP or K herbaria; [4] Tennakoon et al., 2005; [5] Musselman and Visser, 1989; [6] Tennakoon et al., 2007; [7] Musselman, 2000; [8] Beentje and Luke, 2002; [9] Musselman, 1997; [10] Musselman and Visser, 1987; [11] Musselman, 1984; [12] Miller and Morris, 1988; [13] Kuijt, 1969; [14] Visser, 1981; [15] Horwood, 1972; [16] Nyafuono et al., 2000; [17] Maass and Musselman, 2001; [18] Pappe, 1862; [19] Tait and Cunningham, 1988; [20] Nickrent et al., 2002; [21] Visser and Musselman, 1987; [22] Bolin et al., 2005; [23] F.P.S.A., 1931; [24] F.P.S.A., 1926; [25] Seymour et al., 2009; [26] Williams et al., 2011.

observed in this study showed elongated X-shaped bumps up to 10mm long. Habitat and host effects could be responsible for these intra- and/or inter-specific variations.

2.2. Distribution

H. africana occurs from southern Angola, down the coastal regions of Namibia to the Cape and around to the east coast of South Africa (Bolin et al., 2005; Musselman and Visser, 1989; PRE herbarium specimens) (Table 1) (Fig. 3). Published maps for *H. abyssinica* indicate that it occurs from northern Namibia, across most of Angola and the DRC, to Ethiopia, Sudan and the Arabian peninsula (Bolin et al., 2005; Musselman and Visser, 1989). However, ethnobotanical and herbarium evidence collected during this study has ascertained that *H. abyssinica* also occurs in the Northern Cape, KwaZulu-Natal, Gauteng, Mpumalanga and Limpopo Provinces of South Africa (Fig. 3), as well as Swaziland, Mozambique and Malawi (Williams et al., 2011; V.L. Williams, unpublished data; herbarium specimens examined from PRE, NH, PUC, KNP).

Fig. 2. Fruiting bodies of *H. abyssinica*: (A) dry fruits from the Faraday market showing the 4-lobed stigmatic scar on the top of the fruit marking the attachment of the floral tube and the distinctive grooves of the stigma (*Wojtasik 4 & 6* J); (B) evidence of totally epigeous *H. abyssinica* fruits observed on Wabe Island, Okavango Delta, Botswana, showing the round fruit and old floral tube (photo by A.B. Cunningham, 1993). The literature indicates that *H. abyssinica* fruits are entirely hypogeous (i.e. subterranean) (e.g. Seymour et al., 2009), however photograph B and anecdotal evidence from harvesters in Faraday indicate that subpopulations with epigeous fruits occur.

S. sanguinea occurs from the Eastern Cape and KZN to Mpumalanga and Limpopo.

3. Methods

3.1. Study sites

The study sought to confirm the presence of *H. africana*, *H. abyssinica* and *S. sanguinea* in two of the largest traditional medicine markets in South Africa, namely the Faraday (Johannesburg) and Warwick markets (Durban). The markets accommodate approximately 193 and 370 traders/harvesters respectively (Wojtasik, 2009), and traders either purchase medicinal plants from harvesters and other markets, or gather the resources themselves (Mander, 1998; Williams et al., 2007).

3.2. Specimens examined

Several voucher specimens were examined for this study at the National Herbarium, Pretoria (PRE); KwaZulu-Natal Herbarium, Durban (NH); University of KwaZulu-Natal, Pietermaritzburg (NU); North-West University, Potchefstroom (PUC) and Skukuza Herbarium, Kruger National Park (KNP) (Table 2). Samples purchased at Faraday were prepared as voucher specimens and are housed at the C.E. Moss Herbarium, University of the Witwatersrand (J) (Table 2).

3.3. Market surveys

A questionnaire was designed to capture information on the trade of *uMavumbuka* in the markets (Williams et al., 2011; Wojtasik, 2009). Questions asked included: the source of the harvested material; names of the plants under which *uMavumbuka* grows (since it was presumed that traders might not know that *Hydnora* spp. are attached to the roots of hosts); how the harvester recognises the presence of the plant in the wild; and, whether the traders could distinguish between the rhizomes and flowers of *Hydnora* species. Preliminary pre-survey research had found no evidence of *S. sanguinea* in the markets; hence, the questionnaire was designed to capture information on *Hydnora* spp only. Furthermore, no rhizomes resembling *H. africana* were evident in Faraday, therefore a sample of this species purchased from traders in Grahamstown was obtained from A.P. Dold (Selmar Schonland Herbarium).

Pre-survey counts of the number of traders selling *uMavumbuka* indicated there were 100 and 50 traders in Faraday and Warwick respectively with *H. abyssinica* rhizomes. Using

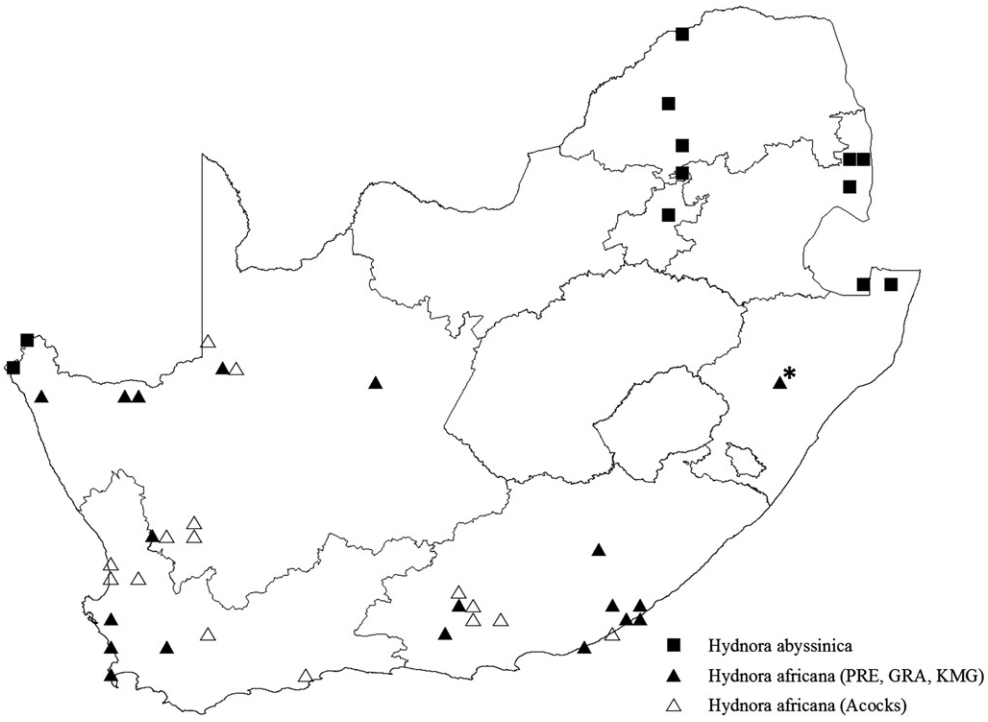

Fig. 3. Known geographical occurrence of *Hydnora abyssinica* and *H. africana* in South Africa and Swaziland. [QDS for *H. abyssinica* obtained from PRE, NH, PUC, KNP and a specimen photographed in the Kruger National Park by O. Maurin from the University of Johannesburg (Fig. 8)]. * Specimen (*Smith 1009* PRE); refer to note in text.

the semi-quantitative questionnaire, a stratified random sample of 46 and 20 traders were interviewed in the Faraday and Warwick markets respectively. Each interview lasted ≤20 minutes, and a Zulu translator assisted with the Warwick survey. The Faraday survey was conducted twice a month from April to July 2009, and the Warwick survey was completed over two consecutive days in June 2009. Samples of *uMavumbuka* were purchased from all the interviewed traders. In addition, unpublished trade data previously obtained from surveys conducted by A.B. Cunningham in the KZN markets between 1986 and 1988, and V.L. Williams in Johannesburg between 1994 and 2001, were incorporated into the results.

3.4. Distribution of Hydnora and host species in South Africa

Ethno-ecological evidence obtained from the market surveys was used to ascertain the harvesting sources of *Hydnora* spp. (principally *H. abyssinica*). Distribution information for *Hydnora* spp. was obtained from SANBI's Integrated Biodiversity Information System (SIBIS; http://sibis.sanbi.org), personal communications (G. Zambatis from Skukuza Herbarium, KNP; O. Maurin from the University of Johannesburg) and *H. abyssinica* specimens in five South African herbaria, namely PRE, NH, NU, PUC and KNP. Potential host species were identified from the common names cited by traders, the host roots attached to the *H. abyssinic*a rhizomes, and notes with the herbarium specimens. The distribution of the positively identified hosts, and hence predicted areas of occurrence of *H. abyssinica*, was compiled from herbarium (primarily PRE from the SIBIS website) and literature sources. ARCGIS was used to produce all the maps from the centroids of the quarter-degree grid squares (QDS).

4. Results and discussion

4.1. uMavumbuka in the muthi markets

One hundred traders in Faraday and 50 traders in Warwick (52% and 14% respectively) sold *uMavumbuka*. *H. africana* was not recorded in either of the markets and the distinctive *S. sanguinea* was observed only once in Faraday after the survey was completed. Hence, we can confirm the presence of *H. abyssinica* in traditional medicine markets in South Africa.

Less than 10% of *uMavumbuka* sellers in each market only harvest and never buy the rhizomes. However, when traders were shown diagrams of typical *H. abyssinica* and *H. africana* flowers with fully patent 4-merous and connivent 3-merous perianth lobes respectively and asked to associate the flowers with the rhizomes they were selling, only 15% of sellers associated the flowers of *H. abyssinica* with the rhizomes of *H. abyssinica*. However, 20% of sellers associated *H. africana* flowers with *H. abyssinica* rhizomes, but two-thirds of these traders had never seen the plants in the wild. The failure of traders to associate *H. abyssinica* flowers with *H. abyssinica* rhizomes might be because when the flowers emerge or under dry environmental conditions, the perianth lobes of *H. abyssinica* fail to separate fully and remain connivent (Table 1) (Fig. 7). A dry *H. abyssinica* flower with upright tepals is difficult to distinguish from that of *H. africana* unless the observer is aware of the differences.

Table 2
Selected list of wild collected and purchased voucher specimens cited and/or examined with locality information. (MP = Mpumalanga; KZN = KwaZulu-Natal; EC = Eastern Cape; NC = Northern Cape).

Species	Voucher number (herbarium)	Month and year	Province/Country	Location	QDS
Wild collected					
H. abyssinica	Van der Schyiff 3464 (KNP)	1957	MP	Skukuza Village, Kruger National Park	2431DC
H. abyssinica	Zambatis 2006 (KNP)	12-1995	MP	Skukuza Village, northern side of rugby field	2431DC
H. abyssinica	Anon. s.n. in KNP 1234 (KNP!)	-	MP	Tshokwane, Kruger National Park	2431DD
H. abyssinica	Ward 1761 (NH)	12-1986	KZN	Tembe Elephant Park	2732AB
H. abyssinica	von Wissell 15073 (PRE)	1971	Swaziland	Ingwavuma River, Nsoko	2731BB
H. abyssinica	Williamson 22463 (PRE)	1996	NC	Richtersveld National Park	2816BB
H. africana	Smith 1009 (PRE)	1937	KZN	Camp Mpofaan between Tugela Ferry and Keats (Bridge) Drift	2830CD
Purchased from muthi markets					
H. abyssinica	Cunningham 2520 (NH, NU)[a]	04-1987	KZN	Purchased at Umlazi medicinal market; originating from the Nongoma district	*Sine loc*
H. abyssinica	Wojtasik 3 (J)	04-2009	KZN	Purchased at Faraday market; reportedly harvested near Josini, KZN	*Sine loc*
H. abyssinica	Wojtasik 4 (J)	05-2009	KZN	Purchased at Faraday market; reportedly harvested near Nongoma, KZN	*Sine loc*
H. abyssinica	Wojtasik 6 (J)	04-2009		Purchased at Faraday market	*Sine loc*
H. africana	Dold *s.n.* (J)	03-2009	EC	Purchased in Grahamstown from medicinal plant traders	*Sine loc*
S. sanguinea	Wojtasik 5 (J)	09-2009	KZN	Purchased at Faraday market; reportedly harvested in uMhlabuyalingana (KZN)	*Sine loc*

[a] Specimen originally identified as *H. africana* and was determined to be *H. abyssinica* in 2009.

4.2. Harvesting localities

Ethno-ecological information from the markets indicated that *H. abyssinica* rhizomes sold in Faraday and Warwick in 2009 were primarily harvested from within the rural Umkhanyakude district of northern KZN, which includes the uMhlabuyalingana and Josini municipalities bordering Mozambique and Swaziland (Fig. 4A). Seventy-three percent of cited harvesting sources were in KZN north of the Tugela River, 17% in KZN south of the Tugela River, 2% in the Eastern Cape, and 8% were unknown (Table 3; Fig. 4A). The harvesting 'hot spot' for *H. abyssinica* is in uMhlabuyalingana north–east of the Mkuzi Game Reserve between Manguzi and Sodwana Bay (46% of cited sources). A voucher specimen collected in Tembe Elephant Park in 1986 (*Ward 1761* NH) was recently determined to be *H. abyssinica*, hence confirming the presence of this species in the district. Another frequently cited location north of the Tugela is the Nongoma municipal area in the Zululand district (19% of citations) (Fig. 4A). In 1987, A.B. Cunningham purchased a specimen of *Hydnora* that originated from the Nongoma area (*Cunningham 2520* NH, NU); this specimen was also determined to be *H. abyssinica* in 2009.

South of the Tugela River, "Mkomazi" was frequently mentioned as a source of *uMavumbuka* (6% of citations) and this could apply to a rural area south-west of the Umkomazi River mouth near the town of Umkomaas (Fig. 4A). While the rhizomes said to have come from Mkomazi are those of *H. abyssinica*, it is possible that *H. abyssinica* and *H. africana* co-occur in this region since an *H. africana* specimen was collected in the Tugela Ferry area (2830CD) in 1937 (*Smith 1009* PRE) (the only *H. africana* specimen known to have been collected in KZN) (Fig. 3). To date, however, no known herbarium specimens of *H. abyssinica* have been collected south of the Tugela. Hence, the collection of voucher specimens in the harvesting areas cited by the *muthi* harvesters is essential to validate the area of occurrence of the taxa. Furthermore, corroborating trader with scientific evidence endorses market surveys as a practical method for inferring the occurrence of resources in the wild.

Unpublished trade records for *uMavumbuka* derived from studies conducted in KZN and Johannesburg between 1986 and 2001 report on rhizomes being harvested throughout KZN and parts of Limpopo and North–West Provinces (Fig. 4B; Table 3). Harvesting in unnamed parts of Swaziland and the Eastern Cape also occurred (Table 3), and a herbarium specimen collected in Swaziland in 1971 (*von Wissell 15073* PRE), recently determined to be *H. abyssinica*, confirms the presence of this species in Swaziland. Rhizomes harvested in the Eastern Cape, however, are probably *H. africana*, given the occurrence of this species in the province (Fig. 3). At the time of the 1986–2001 studies, however, *uMavumbuka* was believed to be either *H. africana* or *S. sanguinea*. Re-examination of the trade records in light of the evidence from this study and the recent re-evaluation of specimens from PRE (by Pieter Winter), NH, NU and PUC, suggests that most of the traded material was probably *H. abyssinica*. However, without scientific evidence to support the occurrence of *H. abyssinica* south of the Tugela and the identity of *Hydnora* spp. present in 'Mkomazi', uncertainty exists regarding the identity of *Hydnora* rhizomes that would have been harvested from southern KZN in the past.

4.3. H. abyssinica host species and distributions

H. abyssinica and *H. africana* reportedly parasitize the roots of *Acacia* spp. and *Euphorbia* spp. respectively (Table 1), hence

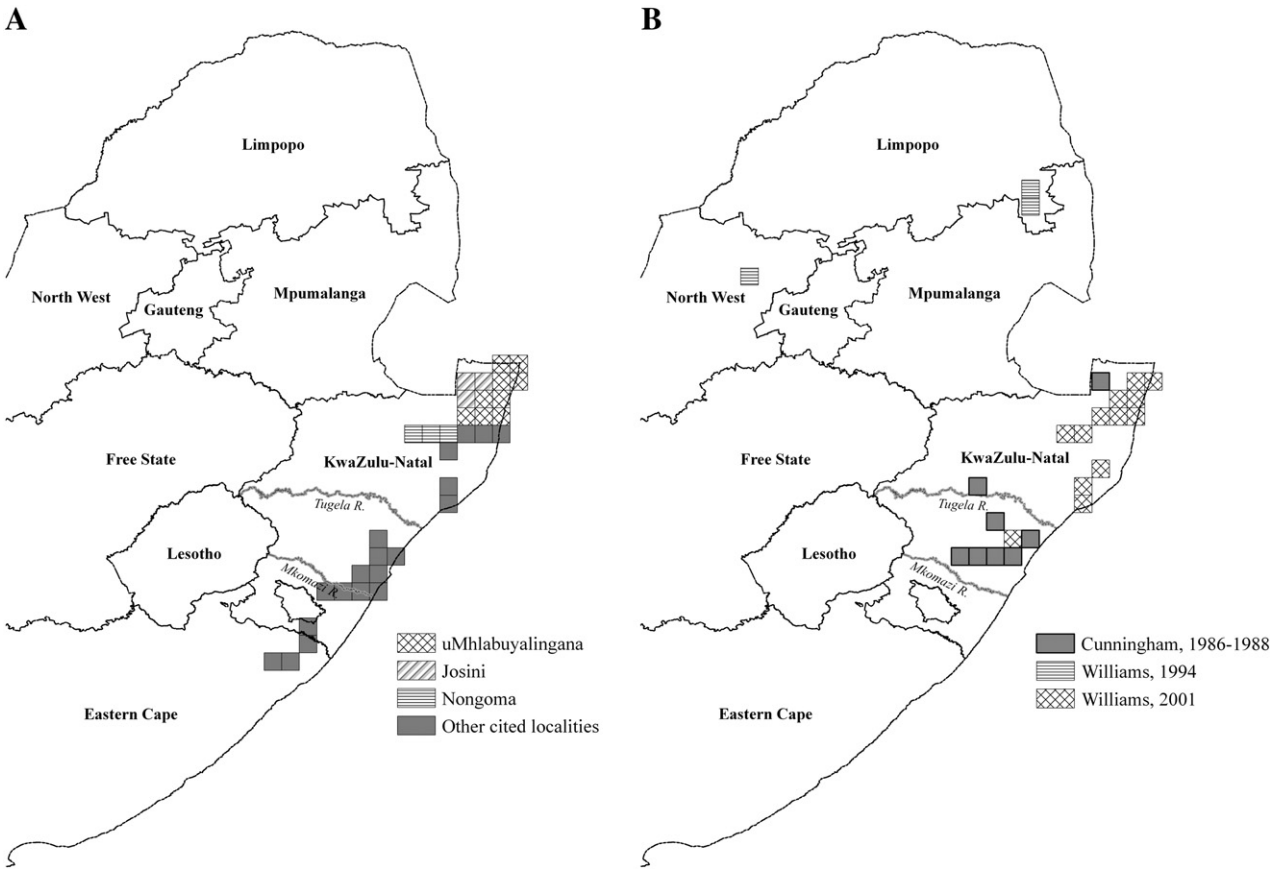

Fig. 4. (A) Harvesting localities for *Hydnora abyssinica* cited by traders in Faraday and Warwick in 2009; (B) Past harvesting sources of *Hydnora* spp. cited in three surveys conducted between 1986 and 2001 by A.B. Cunningham and V.L. Williams.

the identity of the host plant can be used to distinguish between these two *Hydnora* species in South Africa. Fragments of host roots were attached to 83% of the *H. abyssinica* samples purchased from the markets, and *uMavumbuka* was mostly cited as "growing under" *umKhanyakude* (23%) and *umGanu* (22%) (Table 4). In Zulu, *umKhanyakude* means 'light/glowing from afar' and refers to the distinctive yellow bark of the Fever Tree, *Acacia xanthophloea*. The common name of this tree appears never to apply to another species. The bark contains xanthophyll, a photosynthetic yellow-green accessory pigment; this yellow pigment is also present in the root bark and was evident on 93% of the samples that had host root fragments attached to the rhizomes (Fig. 5A). Hence, *A. xanthophloea* was positively identified as a host.

Root fragments of at least one other host species were evident on 7% of the samples (Fig. 6). Despite *umGanu* being the second most cited plant under which *uMavumbuka* grows (Table 4), the roots of neither *Sclerocarya birrea* subsp. *caffra* (Marula) nor *Lannea schweinfurthii* var. *stuhlmannii* (False Marula, *umGanu-nkomo*) resembled the smooth, dark-brown host root fragments present on some of the *H. abyssinica* samples (Fig. 6). While both trees occur in the uMhlabuyalingana/Josini areas, *S. birrea* roots have rough-textured and pale brown outer-bark, reddish inner-bark and a creamy coloured cortex (C. Helm, pers. comm.), and the roots of *L. schweinfurthii* are covered with a dense layer of very fine root hairs (Van Wyk and Gericke, 2000). It therefore appears as if *uMavumbuka* grows in *umGanu* habitat rather than *umGanu* hosting the species. Descriptions of *Acacia karroo* roots in the literature also did not match the appearance of the unidentified host roots, even though *A. karroo* is mentioned on herbarium vouchers (e.g. *Williamson 22463* PRE) and was cited as a tree that *uMavumbuka* grows under (Table 4).

In total, traders cited the common names of 14 plants corresponding with approximately 20 plant species under which they had witnessed *uMavumbuka* growing; most of these plants correspond with species from the Fabaceae (Table 4). Common names corresponding with the Euphorbiaceae were also mentioned. Included in the list of common names were *iNgwavuma* (*Elaeodendron transvaalense*) and *iHlalanyosi-elimhlope* (*Schlechterina mitostemmatoides*), species which occur within cited northern KZN *H. abyssinica* harvesting localities and habitat, but which are very unlikely to be hosts. Given that *H. abyssinica* has an extensive, subterranean rhizome system that spreads away from the host, and that Fabaceae with well-developed lateral- and surface-root systems have been observed [e.g. up to 20 m from the base of the tree in *Burkea africana* Hook. and to 16 m in *Acacia tortilis* (Forrsk.) Hayne] (Coughenour et al., 1990; Rutherford, 1983), it is probable that *H. abyssinica* will grow beyond the crown border of the host tree. Hence, non-Fabaceae species might be

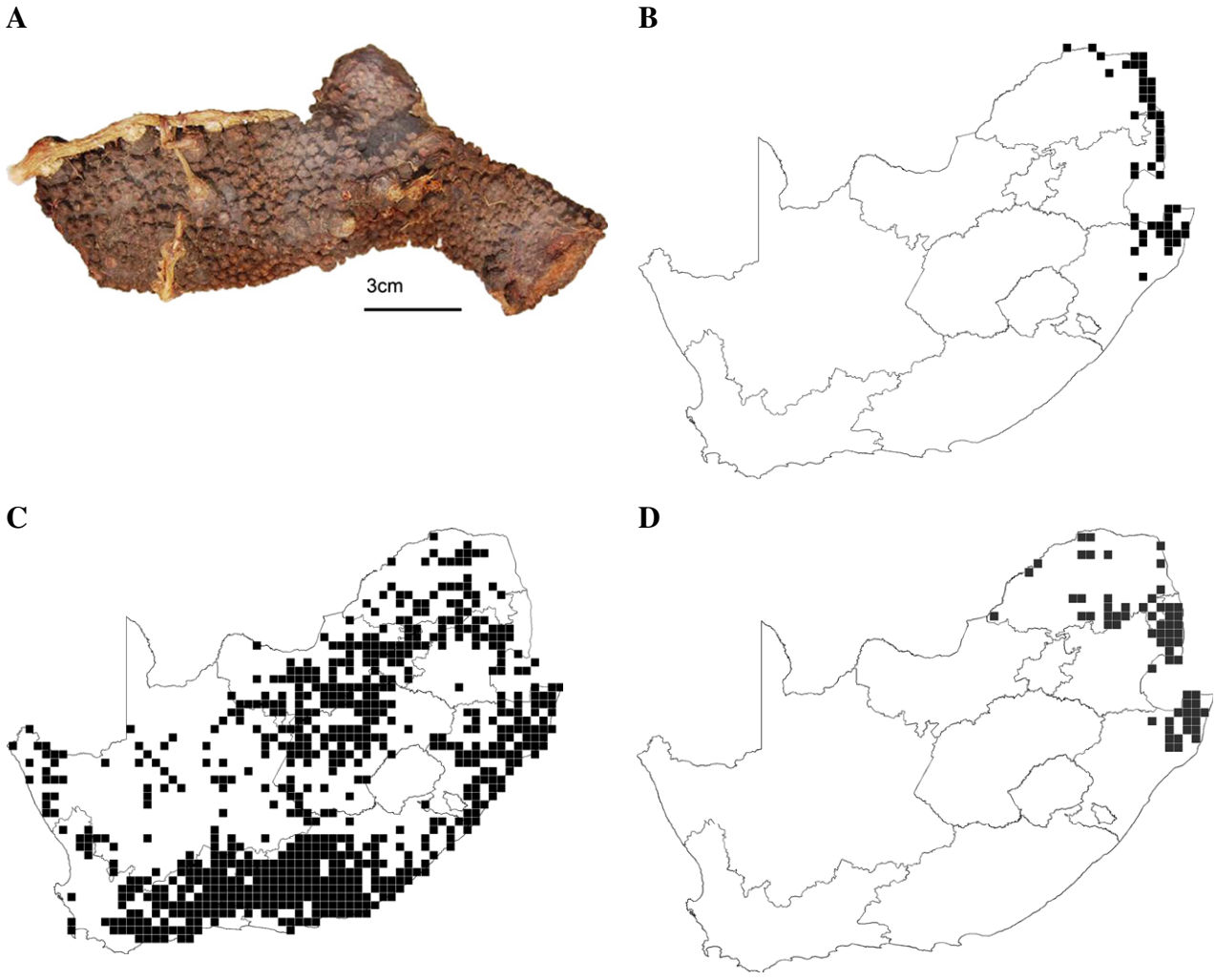

Fig. 5. *Acacia* species identified as *Hydnora abyssinica* hosts in South Africa. (A) *Acacia xanthophloea* roots attached to the rhizome on the haustoria and showing the distinctive yellow root bark; (B) distribution of *A. xanthophloea* (QDS from PRE; Pooley, 1993; Schmidt et al., 2002); (C) distribution of *Acacia karroo* (QDS from http//:sibis.sanbi.org); (D) distribution of *Acacia grandicornuta* (QDS from http//:sibis.sanbi.org; Schmidt et al., 2002).

erroneously associated as hosts unless the rhizomes are excavated to determine the actual host. At Tshokwane in the Kruger National Park, for example, *H. abyssinica* was photographed growing under *Berchemia discolor* (Klotzsch) Hemsl. (Rhamnaceae) (Fig. 7), a species not known to be a host.

Fig. 6. Unidentified host roots with dark brown root bark attached to *Hydnora abyssinica* rhizome (*Wojtasik 4* J).

Since holoparasites are host-dependent, the distribution of the host species may indicate areas of suitable habitat for *H. abyssinica*. *A. xanthophloea*, the most frequently observed host in the markets, occurs from northern KZN through Mpumalanga and Limpopo and the border with Swaziland and Mozambique (Fig. 5B). The trees tend to grow in seasonally flooded low-lying localities along rivers, swamps and pans and on alluvial soils in riverine woodland (http://sibis.sanbi.org; Botha et al., 2002). Several traders mentioned that *H. abyssinica* grows near water, and the soil brushed off the rhizomes purchased at the market was primarily greyish-brown and sandy/alluvial in nature. A few samples had more reddish soil, indicating rhizomes that had been harvested from under trees in a different habitat. Other species that have been positively identified as hosts on vouchered herbarium specimens in South Africa, and which may indicate areas where *H. abyssinica* grows, include *A. karroo* (*Williamson 22463* PRE) (Fig. 5C) and *A. grandicornuta* (*van der Schyiff 3464* KNP; *Zambatis 2006* KNP) (Fig. 5D).

A technology that may assist with the identification of host roots attached to *Hydnora* spp. rhizomes purchased from traditional medicine markets in the future, is DNA barcoding.

Fig. 7. Emerging flowers of *Hydnora abyssinica* observed growing under *Berchemia discolor* (Klotzsch) Hemsl. (Rhamnaceae) at Tshokwane, Kruger National Park (2431DD), by Guin Zambatis (KNP Herbarium, Skukuza) in December 2009. White osmophores are evident at the tips of the 4-merous salmon-coloured perianth lobes. There are three *H. abyssinica* specimens at KNP herbarium (*van der Schyiff 3464* KNP; *Zambatis 2006* KNP; *Anon. s.n.* KNP!), one collected in 1957.

The technique uses short segments of DNA ('barcodes') to identify unknown specimens to species, and is especially useful as a forensic tool when there are insufficient diagnostic morphological features (Sass et al., 2007). To this end, we are currently collaborating with the University of Johannesburg and the DNA Barcoding group to identify, where possible, the host roots attached to *H. abyssinica* rhizomes purchased from the Faraday and Warwick markets in 2009 and 2010.

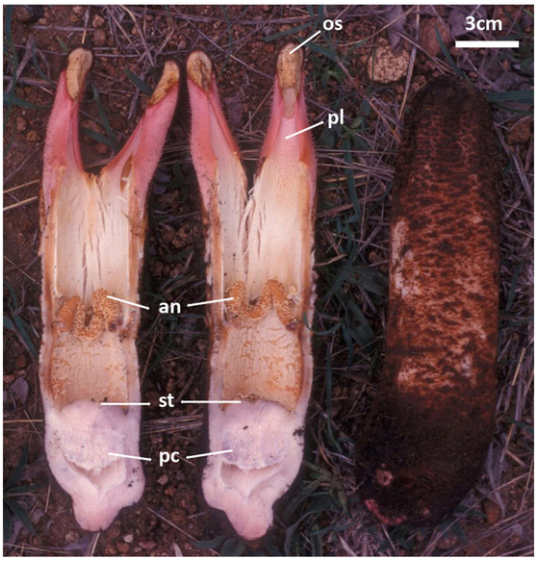

Fig. 8. Longitudinal sections of a 4-merous *H. abyssinica* flower photographed in the Biyamiti area of the Kruger National Park (2531BC) by O. Maurin of the University of Johannesburg in December 2005. The osmophore (*os*) is at the tip of the perianth lobe (*pl*) on the interior surface of each tepal. The fused 4-lobed antheral ring (*an*) is at the base of the androecial chamber, and the 4-lobed stigmatic 'cushion' (*st*) is at the base of the gynoecial chamber above the ovary and the placenta (*pc*). The flower is attached to the rhizome by the stalk at the base of the ovary. The flower on the extreme right of the picture is intact and shows the exterior appearance of the flower.

Table 3
Cited harvesting sources of *Hydnora* spp. All plants recorded in 2009 were *H. abyssinica*. Plants recorded in Mpumalanga, Limpopo, Swaziland and Mozambique in 1994 and 2001 are probably *Hydnora abyssinica*. Plants harvested in KwaZulu-Natal in 1988, 1994 and 2001 are either *H. abyssinica* or *H. africana*. The quarter-degree squares (QDS) of the specific areas cited by the traders are listed (see Fig. 4).

Cited harvesting source localities	% of cited areas			
	1988[a] (n=52)	1994[b] (n=23)	2001[c] (n=47)	2009[d] (n=66)
South Africa				
KwaZulu-Natal	88%	48%	68%	90%
Eastern Cape			2%	2%
Limpopo		4%		
North West		4%		
Swaziland		9%		
Mozambique			2%	
Unknown source	12%	35%	28%	8%

Specific areas cited include:
[a]Cunningham, A.B., 1986-1988 (unpublished data from KZN muthi shops).
KWAZULU-NATAL.—2732 (Ubombo): Josini (-AA). 2830 (Dundee): Pomeroy (-CB). 2930 (Pietermaritzburg): Greytown; Umvoti (-BA). Taylor's Halt (-CA). Pietermaritzburg (-CB). Inchanga (-DA). Claremont; Durban, Isipingo (-DD). 2931 (Stanger): Ndwedwe (-A_).
[b]Williams, V.L., 1994 (unpublished data from Johannesburg muthi shops)
MPUMALANGA.—2431 (Acornhoek): Bushbuckridge (-C_).
NORTH WEST.—2527 (Rustenburg): Rustenburg (-CA).
[c]Williams, V.L., 2001 (unpublished data from Faraday muthi market).
KWAZULU-NATAL.—2731 (Louwsburg): Nongoma (-DC/DD). 2732 (Ubombo): uMhlabuyalingana (including KwaJobe, KwaMduka, Lebombo, Mkuze, Obonjeni). 2831 (Nkandla): Empangeni (-DB/DD). 2832 (Mtubatuba): Mtubatuba (-AC). 2929 (Underberg): Mkomazi (including river catchment) (-D_). 2930 (Pietermaritzburg): Ndwedwe (including Mbumbulu) (-BD/DB).
[d] Wojtasik, E.M., 2009 (Faraday and Warwick muthi markets).
KWAZULU-NATAL.—2632 (Bela Vista): Manguzi (-DC/DD). 2731 (Louwsburg): Nongoma (-DC/DD). 2732 (Ubombo): uMhlabuyalingana, including: Ngwavuma (-AA), Josini (-AC), Mpakathini (-AD), Manguzi (-BA), Mseleni (-BC), Mkuze (-CA), KwaJobe (-CB), Sodwana (-DA). 2831 (Nkandla): Ngolotshe (-BB), Empangeni (-DB/DD). 2929 (Underberg): Mkomazi (-D_). 2930 (Pietermaritzburg): Ndwedwe (including Mbumbulu) (-BD/DB), Emaweleni (-DD). 3029 (Kokstad): Harding (-DB). 3030 (Port Shepstone): Ixopo (-AA).
EASTERN CAPE.—3029 (Kokstad): Bizana (DD), 3129 (area): Flagstaff (-AB/BA).

4.4. Locating Hydnora in the wild

Because of their cryptic nature and the seasonal appearance of flowers, *Hydnora* is rarely encountered and collected (Tennakoon et al., 2007). Given the paucity of herbarium information on the occurrence of *H. abyssinica* on the eastern seaboard of southern Africa, the collection of voucher specimens is essential—especially in areas where the cited harvesting localities overlap with known host species. Traits that harvesters generally look for to indicate the presence of *Hydnora* include: rhizome protrusion (especially after rain and thunder), bulging and cracking soil, and the presence of flowers and/or round fruit above the soil surface. A few traders

Table 4
Common names and probable species that traders said *uMavumbuka* "grows under". Names could either refer to potential hosts or species within the habitat growing nearby.

Common name	Probable species[a]	Family	Number of trader citations for the common name (n=64)
umKhanyakude	*Acacia xanthophloea* Benth.	Fabaceae	15
umGanu	i) *Sclerocarya birrea* (A.Rich.) Hochst. subsp. *caffra* (Sond.) Kokwaro.	Anacardiaceae	14
	ii) *Lannea schweinfurthii* (Engl.) Engl. var. *stuhlmannii* (Engl.) Kokwaro [b]	Anacardiaceae	
iHluze	*Schotia brachypetala* Sond.	Fabaceae	5
umuNga	*Acacia karroo* Hayne	Fabaceae	3
um(n)Gamanzi	*Acacia caffra* (Thunb.) Willd.	Fabaceae	2
	Acacia robusta Burch. subsp.	Fabaceae	
umKhaya	i) *Acacia burkei* Benth.	Fabaceae	2
	ii) *Acacia nigrescens* Oliv.	Fabaceae	
	iii) *Acacia sieberiana* DC. var. *woodii* (Burtt Davy) Keay & Brenan	Fabaceae	
uGagane	i) *Acacia ataxacantha* DC.	Fabaceae	2
	ii) *Acacia kraussiana* Meisn. ex Benth.	Fabaceae	
	iii) *Dichrostachys cinerea* (L.) Wight & Arn.	Fabaceae	
iNgwavuma	*Elaeodendron transvaalense* (Burtt Davy) R.H.Archer	Celastraceae	2
umHlonhlo	Euphorbia spp.	Euphorbiaceae	2
iLethi	i) *Phyllanthus meyerianus* Müll.Arg.	Euphorbiaceae	2
	ii) *Croton gratissimus* Burch. var.	Euphorbiaceae	
	iii) *Morella serrata* (Lam.) Killick	Myricaceae	
	iv) *Gerrardina foliosa* Oliv.	Flacourtiaceae	
umThombothi	*Spirostachys africana* Sond.	Euphorbiaceae	1
iHlalanyosi-elimhlope	*Schlechterina mitostemmatoides* Harms.	Passifloraceae	1
umKhiwani	i) *Ficus sur* Forssk.	Moraceae	1
	ii) *Ficus polita* Vahl subsp. *polita*	Moraceae	
	iii) *Ficus sycomorus* L. subsp.	Moraceae	
umZaneno	*Olinia radiata* Hofmeyr & E.Phillips	Oliniaceae	1
Plus an additional 6 unidentified common names cited once each			

[a]Numbered species refer to multiple species with the same common name.
[b]called *umGanu-nkomo*, but could be shorted to *umGanu*.

select harvesting sites they have visited before and/or look for plants they know *Hydnora* grows under.

Two harvesters were more descriptive about how to locate *Hydnora*. One said *uMavumbuka*: a) is always found near trees, b) grows under *umKhanyakude* (*A. xanthophloea*) in uMhlabuyalingana (suggesting *H. abyssinica*), and c) grows near Ixopo, Harding and Mkomazi under *umGanu* and *umuNga* (but specifically not under *umKhanyakude* in the region). The second harvester said the best time to find *uMavumbuka* was from August to January, especially after rain when the soil was soft and the plants flowered. He further indicated that the rhizomes grow back quickly after harvesting.

There are subtle differences in *Hydnora* spp. rhizome morphology, and most traders presumed (when shown the *H. africana* rhizome) that *H. africana* and *H. abyssinica* were the same species. Soil type and locality were suggested as reasons why the rhizomes looked slightly different, with *H. africana* said to occur in less fertile soil further away from the sea. *H. abyssinica* rhizomes, however, were said to occur in fertile soil closer to water. Some of the information on variations in *Hydnora* morphology, habitat and distribution obtained from the harvesters indicate that there are at least two different species harvested in eastern South Africa, for example *uMavumbuka* growing under *umHlonhlo* (*Euphorbia* spp., Table 4) would be *H. africana* not *H. abyssinica*. However, host and habitat effects, as well as natural variation, are likely to cause intra-specific variations as well. Whether these distinctive character differences (e.g. evidence of epigeous fruits in *H. abyssinica* subpopulations and variable bump shape) also indicate new species, subspecies or varieties of *Hydnora* is unclear, since the significance of the variation is not known without further investigation of this 'new' southern African subpopulation.

5. Conclusion

H. abyssinica rhizomes are very prevalent in the Faraday and Warwick *muthi* markets, and appear to have been traded extensively for traditional medicine for many years. However, no published accounts of its occurrence in KZN and other parts of South Africa exist—primarily because several *H. abyssinica* herbarium specimens were incorrectly identified as *H. africana*, and the species was therefore assumed, by default, to not occur in eastern southern Africa. The knowledge of the harvesters and traders, and the information derived from specimens purchased at the *muthi* markets, offered insight into the potential distribution, ecology and characteristics of *H. abyssinica* in South Africa. Herbarium evidence further validated the ethno-ecological evidence, and confirmed that *H. abyssinica* occurs in KZN and hence further south and east than previously known. Furthermore, *H. abyssinica* specimens at the Skukuza Herbarium (KNP) have confirmed that the species also occurs in the Kruger National Park.

Despite *H. africana* not being observed in the Johannesburg and Durban *muthi* markets during the 2009 surveys, it is sold in the Eastern Cape markets adjacent to its area of occurrence (Dold et al., 2003), and has been recorded in KZN markets in the past (Von Ahlefeldt et al., 2003). There is also evidence that *H. africana* rhizomes harvested in the Eastern Cape were sold in

Johannesburg in 2001. However, the absence of this species in the markets in 2009 raises questions on its current accessibility to harvesters supplying the Faraday and Warwick markets, since some traders are aware of plants with similar vegetative features occurring in areas south of the Tugela River.

Priorities with respect to future *Hydnora* research in South Africa are: to verify the occurrence and abundance of *Hydnora* spp. in areas exploited by traditional medicine harvesters; to identify the host species and infer the distribution and areas of suitable habitat where subpopulations may be located; and, to investigate variations in *H. abyssinica* rhizome, flower and fruit morphology between different subpopulations to establish whether observed variations are significant at a taxonomic level. For an important medicinal plant in South Africa, these data would help assess the condition of the resource in the wild and hence the potential vulnerability of *Hydnora* spp. to over-exploitation and unsustainable harvesting.

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